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THESIS

THE BATTLE GROUP LOGISTICS COMPARATIVE ANALYSIS MODEL (BGLCAM): A COMPARATIVE ANALYSIS TOOL FOR MULTI-BATTLE GROUP LOGISTICS SUPPORT

by

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September, 1997

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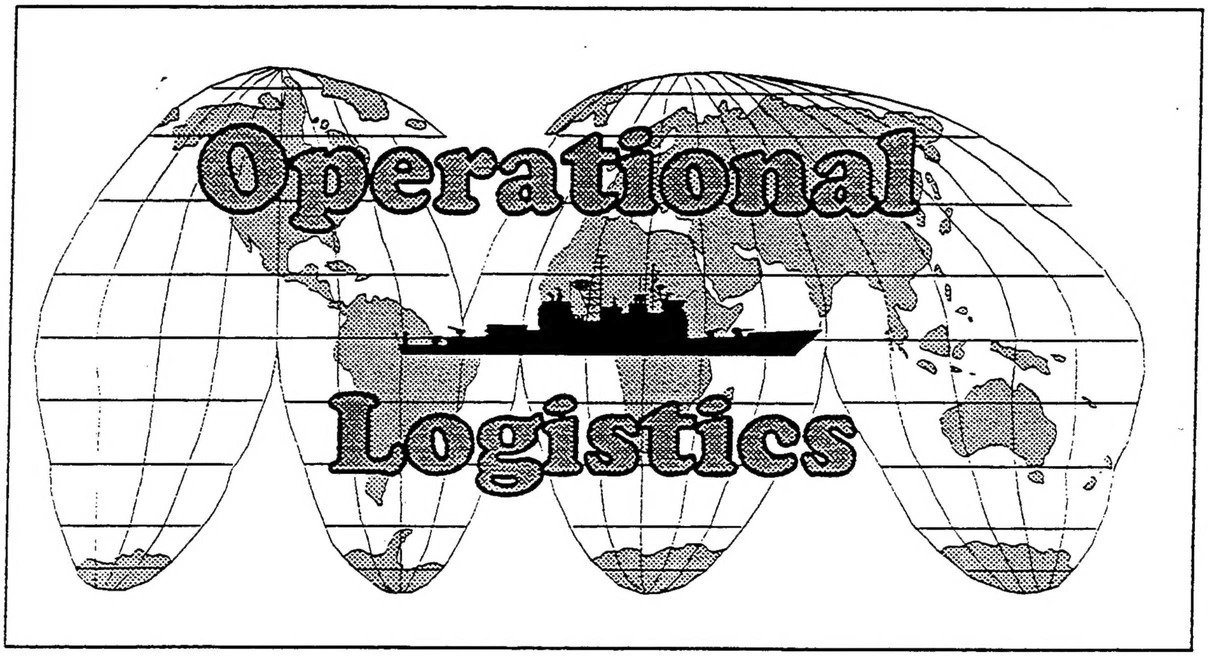
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This thesis develops a computer simulation for modeling the logistical support of multiple naval battle groups in a peacetime or wartime setting. The simulation model, written in Microsoft Visual Basic Version 5.0, allows the user to create any number of naval battle groups containing multiple combatants that are located by latitude and longitude. Each battle group operates with one or two assigned station supply ships, i.e., a fast combat support (AOE) ship, or a fleet oiler (AO) ship and ammunition (AE) ship, respectively. Additionally, the user can create any number of Forward Logistics Base (FLB) ports and Continental United States (CONUS) ports, each having any number and type of shuttle supply ships assigned to them. Every ship and port has four major supply categories: F44 (aviation fuel), F76 (diesel fuel marine), ammunitions, and stores. The combatant's supplies are consumed over the specified time frame based on a randomly selected F76 rate, a fixed user-inputted stores rate and, if desired, multiple user-inputted F44 and ammunition rates. The multiple user-inputted F44 and ammunition consumption rates capability enables the user to model a naval battle based on any previously developed Tactical Warfare (TACWAR) or similar scenario involving aircraft carrier and/or amphibious battle groups.

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THE BATTLE GROUP LOGISTICS COMPARATIVE ANALYSIS MODEL (BGLCAM): A COMPARATIVE ANALYSIS TOOL FOR MULTI-BATTLE GROUP LOGISTICS SUPPORT

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ABSTRACT

This thesis develops a computer simulation for modeling the logistical support of multiple naval battle groups in a peacetime or wartime setting. The simulation model, written in Microsoft Visual Basic Version 5.0, allows the user to create any number of naval battle groups containing multiple combatants that are located by latitude and longitude. Each battle group operates with one or two assigned station supply ships, i.e., a fast combat support (AOE) ship, or a fleet oiler (AO) ship and ammunition (AE) ship, respectively. Additionally, the user can create any number of Forward Logistics Base (FLB) ports and Continental United States (CONUS) ports, each having any number and type of shuttle supply ships assigned to them. Every ship and port has four major supply categories: F44 (aviation fuel), F76 (diesel fuel marine), ammunitions, and stores. The combatant's supplies are consumed over the specified time frame based on a randomly selected F76 rate, a fixed user-inputted stores rate and, if desired, multiple user-inputted F44 and ammunition rates. The multiple user-inputted F44 and ammunition consumption rates capability enables the user to model a naval battle based on any previously developed Tactical Warfare (TACWAR) or similar scenario involving aircraft carrier and/or amphibious battle groups.

THESIS DISCLAIMER

The reader is cautioned that the computer program developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the program is free of computational and logical errors, they cannot be considered validated. Any application of this program without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

This thesis develops and demonstrates the Battle Group Logistics Comparative Analysis Model (BGLCAM), a low-resolution stochastic simulation that models the basic naval concept of operations for sustaining a carrier battle group in the area of operations (AO). When an aircraft carrier battle group is on station, the battle group is generally operating with one or two "station ships", ships which remain with the battle group. The preferred station ship is the fast combat support (AOE) ship because of her speed and multi-product support capabilities. The AOE ship is able to replenish the surface combatants with fuel, ordnance, spare parts, and subsistence commodities. If there is not an AOE ship available, then one can generally expect to see an oiler (AO) ship and an ammunition (AE) ship operating together as station ships with the battle group.

When the station ship needs replenishment, combat logistics force (CLF) ships bring the necessary supplies from a forward logistics base (FLB) to them, enabling them to remain on station with the battle group. These CLF "shuttle ships" which replenish the station ship are usually single-product ships, such as AO ships, AE ships, and stores (AFS) ships. Furthermore, there are U.S. chartered, Ready Reserve Fleet, and other vessels acting as shuttle ships that bring the necessary supplies from ports around the world to the FLBs.

The simulation model, written in Microsoft Visual Basic Version 5.0, models the basic concept of operations for battle group logistical support described above. It allows the user to create any number of naval battle groups containing multiple combatants that are located by latitude and longitude. Each battle group operates with one or two

assigned station supply ships, i.e., a fast combat support (AOE) ship, or a fleet oiler (AO) ship and ammunition (AE) ship, respectively. Additionally, the user can create any number of Forward Logistics Base (FLB) ports and Continental United States (CONUS) ports, each having any number and type of shuttle supply ships assigned to them. Every ship and port has four major supply categories: F44 (aviation fuel), F76 (diesel fuel marine), ammunitions, and stores. The combatant's supplies are consumed over the specified time frame based on a randomly selected F76 rate, a fixed user-inputted stores rate and, if desired, multiple user-inputted F44 and ammunition rates. The multiple user-inputted F44 and ammunition consumption rates capability enables the user to model a naval battle based on any previously developed Tactical Warfare (TACWAR) or similar scenario involving aircraft carrier and/or amphibious battle groups.

An example of the use of the BGLCAM for analysis is presented in this thesis. The results of the example are given in this report to show the user of BGLCAM the different ways in which the simulation model can be used. Since BGLCAM provides a theater-level representation of battle group logistics support, and not an operational-level view, it is recommended that it be used only for its designed purposes.

I. INTRODUCTION

The sole purpose of battle group logistics support is to replenish naval combatants at sea. It is this "at sea" logistics support that enables United States naval combatants to remain on location when and where our political and military leaders need them. There are obvious benefits as a result of this ability, including the capability to generate a formidable military force, in the form of a naval battle group, off the coast of almost any nation in the world in a relatively short amount of time, with the force remaining on location for months on end by the means of replenishment at sea. If it weren't for at sea replenishment, our country's foreign policy of forward presence from the sea would be diminished, if not non-existent, around much of the world.

This logistical support of naval forces at sea can be divided into three basic parts: support to the battle group while in transit to the area of operations (AO), sustainment of the battle group while in the AO, and support to the battle group on its return home. Of the three basic parts, this thesis deals with the second one, the sustainment of naval forces operating in the AO.

A. SUSTAINMENT OF NAVAL FORCES IN THE AREA OF OPERATIONS

The following is a basic summary of today's naval concept of operations for sustaining a carrier battle group in the AO, which borrows heavily from a paper by Dr. Schrady, et al, [Ref. 1]. When an aircraft carrier battle group is on station, the battle group is generally operating with one or two "station ships", ships which remain with the battle group. The preferred station ship is the fast combat support (AOE) ship because of her speed and multi-product support capabilities. The AOE ship is able to replenish the surface combatants with fuel, ordnance, spare parts, and subsistence commodities. If there is not an AOE ship available, then one can generally expect to see an oiler (AO) ship and an ammunition (AE) ship operating together as station ships with the battle group.

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acting as shuttle ships that bring the necessary supplies from ports around the world to the FLBs.

This basic concept of operations for battle group logistics support is exactly what its name implies: a fundamental approach to replenishing ships at sea. It doesn't imply that everything a naval combatant will need can be replenished at sea, nor does it imply that every time a carrier battle group deploys with a station ship that all of her combatants will invariably come alongside the station ship for resupply. There may be certain operations taking place that would preclude a surface combatant from joining up with the station ship; having one of the combatants of the battle group pull into a port for resupply may be more beneficial to the overall operations. Those familiar with naval operations may strive for a totally "at sea" supportable battle group but, as it stands today, there are certain physical limitations that prohibit our forces from being resupplied with certain kinds of ordnance, and there are specific repairs that can only be completed in port.

B. INNER BATTLE GROUP LOGISTICS

The following brief summary of inner battle group logistics (logistics within the battle group) borrows heavily from [Ref. 1] and [Ref. 2]. Each combatant within the battle group is assigned a relative location within the battle group formation based on its capabilities. As a combatant's supplies are expended and it becomes necessary for resupply at sea, there are several methods from which to choose to replenish that ship. Each method comes with certain strengths and weaknesses. The available replenishment methods include the Delivery Boy, Service Station, Circuit Rider, Chain Saw, and Gasoline Alley. Of the several tactics available there are two that stand at opposite ends of the spectrum: the Delivery Boy and Service Station methods.

The Delivery Boy tactic has the station ship traveling to the combatant so that the combatant can maintain its relative position within the battle group formation. The advantages to this approach comprise having the formation stay intact, minimal off-station time for the combatant, and separating the station ship and aircraft carrier from one another within the formation. Disadvantages include the need for a high-speed station ship, greater vulnerability to the station ship to attacks from the enemy, the possible need for a permanent escort to travel with the station ship, and situations where the Delivery

Boy tactic is infeasible due to the battle group's speed and the ships' positions relative to each other.

On the other end of the spectrum is the Service Station tactic where the station ship is positioned within the formation near to the aircraft carrier and the combatants travel to her for resupply. The advantages of this method include maximum protection to the station ship, no need for a high-speed station ship, and the fact that it is easier to keep the aircraft carrier replenished. Disadvantages include the fact that the combatant has to leave its relative position within the battle group, thus placing the battle group, as a whole, to greater risk. Furthermore, the enemy is more likely to sink the carrier and the station ship in a single fight. Finally, it is more difficult to schedule and coordinate underway replenishments (UNREPs).

C. THEATER LEVEL ANALYTIC SIMULATION MODELS

Today within the Department of Defense (DoD) there is a great effort amongst the modeling and simulation community to seamlessly integrate computer-driven logistics models with combat models. One such effort, called the Warfighting and Logistics Technology Assessment Environment (WLTAE), is currently being conducted by the Johns Hopkins University Applied Physics Lab (JHU/APL). This and other similar efforts are being pursued so that the DoD can obtain simulation models that more resemble the real nature of things in warfare, i.e., models that model combat and logistics.

Out of the available theater level analytic simulation models that model combat, there are several that model naval warfare. These range from very simplistic to highly detailed models. Most of these models, however, model battle group logistics and in-theater support little, or not at all.

Because of these limitations there are little or no means to analyze different aspects of battle group logistics within the context of results generated by one of these combat models. Many questions like the following cannot be answered by such analytic combat simulations. Can the naval battle groups operating in support of the ground campaign be logistically supported? How many shuttle ships are necessary to support the battle groups? Can the carrier battle group be adequately sustained by the CLF shuttle ships operating out of a more distant port? Can we support the battle groups with a different mix of shuttle ships allocated differently amongst the FLBs? How much difference in time

will the combatants spend in underway replenishment if they operate with a different type of station ship?

D. THE BATTLE GROUP LOGISTICS COMPARATIVE ANALYSIS MODEL (BGLCAM)

BGLCAM was designed to help answer the above questions and others like it. This computer simulation model provides a tool for analyzing various aspects of naval battle group logistics using the results of a combat model. Its primary measures of effectiveness (MOEs) are the mean number of UNREPs, the mean UNREP time for each combatant and station ship, and the mean inter-event time for each ship to join up with another ship for replenishment. Other information can be easily extracted from a model run by importing the output file into a Microsoft Excel spreadsheet (see Figure 1).

The motivation to develop this comparative analysis simulation model came as a result of considering the feasibility or infeasibility of logistically supporting naval combatants operating in a Tactical Warfare (TACWAR) scenario. In TACWAR and other combat simulation models, many of the different categories of supplies are consumed at certain rates. These consumption rates are in units of pounds per man per day. Thus, BGLCAM has the user scripting the naval battle scenario according to the rates of ordnance and aviation fuel consumed in the commonly seen units of pounds per man per day. Furthermore, BGLCAM allows for these consumption rates to be entered by time periods over the course of the battle for each combatant.

What follows is a detailed description of the BGLCAM properties, a model application, and some suggested model improvements.

Day	Name	BG#	F44C (bbls)	F44O (bbls)	F76C (bbls)	F76O (bbls)	AmmoC (tons)	AmmoO (tons)	StoresC (tons)	StoresO (tons)	Receiver	JoinupTime (day)	BreakAwayTime (day)	Supplier	PortReturnTime (day)	SendingPort
6	CV-2	2	46272	36152.7	55363	39805.84	900	900	1575	1470.001						
6	CV-2	2	46272	36152.7	55363	39805.84	900	900	1575	1470.001						
6.019525	CV-2	2	46272	36119.77	55363	39766.79	900	900	1575	1469.659						
6.020408	CV-2	2	46272	36118.28	55363	39764.52	900	900	1575	1469.644						
6.103179	CV-2	2	46272	35978.68	55363	39551.71	900	900	1575	1468.196						
6.208338	CV-2	2	46272	35801.32	55363	39176.18	900	900	1575	1466.358						
6.5	CV-2	2	46272	35309.41	55363	38675.98	900	900	1575	1461.252						
6.5	CV-2	2	46272	35309.41	55363	38675.98	900	900	1575	1461.252						
6.5											CV-2	6.511287	6.661326	AO-2		
6.5											CV-2	6.512615	6.911054	AE-2		
6.5001	CV-2	2	46272	35309.29	55363	38675.72	900	900	1575	1461.25						
6.511287	CV-2	2	46272	35309.29	55363	38656.53	900	900	1575	1461.054						
83.61041	AO-2	2	83000	65041.91	100000	46070.25	600	579.0402	300	138.9591						
83.63995	AO-2	2	83000	64911.4	100000	44557.57	600	579.0402	300	137.4359						
83.79015	AO-2	2	83000	64911.4	100000	44484.72	600	579.0402	300	137.3308						
84	AO-2	2	83000	66911.4	100000	54652.29	600	600	300	252.5069						
84	AO-2	2	83000	66911.4	100000	54652.29	600	600	300	252.5069						
84											AO-2	84.94423	85.27787	T-AO-YO1a	87.05076	
84.4446	AO-2	2	83000	66911.4	100000	53491.88	600	600	300	252.1957						
84.5	AO-2	2	83000	66911.4	100000	53448.12	600	600	300	252.1569						
87	Yokohama		1.78E+09	8.91E+08	3.23E+09	1.61E+09	20000	5497.895	10000	9854.248						
87.5	Yokohama		1.78E+09	8.91E+08	3.23E+09	1.61E+09	20000	5497.895	10000	9800.734						
88	Yokohama		1.78E+09	8.91E+08	3.23E+09	1.61E+09	20000	7497.895	10000	10000						
88.0006											Yokohama	95.74368	96.67773	BH-PH1b	105.5191	Pearl Harbor
88.5	Yokohama		1.78E+09	8.91E+08	3.23E+09	1.61E+09	20000	7497.895	10000	10000						
89	Yokohama		1.78E+09	8.91E+08	3.23E+09	1.61E+09	20000	7497.895	10000	10000						
89.5	Yokohama		1.78E+09	8.91E+08	3.23E+09	1.61E+09	20000	7497.895	10000	10000						
90	Yokohama		1.78E+09	8.91E+08	3.23E+09	1.61E+09	20000	7497.895	10000	10000						

Figure 1. Spreadsheet Output

II. THE BGLCAM PROPERTIES

A. GENERAL OVERVIEW

BGLCAM seeks to capture the major aspects of the basic concept of operations for battle group logistical support in a peacetime or wartime setting. Being an object-oriented simulation program, there are five object types: Combatant Ships, Supply Station Ships, Supply Shuttle Ships, CONUS Ports, and Forward Logistic Bases (see Appendix). Each of the five object types are characterized by at least four major categories of attributes: ship propulsion fuel (F76), aviation fuel (F44), ammunition (Ammo), and Stores. Since the model does not differentiate amongst different types of ordnance, the reality of combatants having to return to port for certain types of ordnance is not modeled. Though a drawback, the model still captures enough of reality to provide some valuable insights to battle group logistical support. Lastly, if the user desires a higher level of detail in the output of results, he can change the frequency of updates and the duration of the battle, accordingly.

For purposes of clarity the following model description is broken up into three parts: Combatant Resupply, Station Ship Resupply, and FLB Port Resupply (see Figure 2).

B. COMBATANT RESUPPLY

The model allows the user to create multiple battle groups containing one or more combatants. Each battle group must have an AOE ship or an AO and AE ship operating with it. The ships' supplies are consumed at a certain rate depending on supply category, user input, and events that are taking place. Every occurrence of an event updates the onhand supply levels for the ships and ports.

Whenever a combatant generates a request for any one of the four major supply categories and the request is not denied by the station ship, one of the following four boolean variables within the simulation program is set to "True", depending on which supply is requested: "F44IsTasked", "F76IsTasked", "AmmoIsTasked", or "StoresIsTasked". (Hereafter, these four boolean variables are referred to collectively as the "request boolean variables"). If no requests have been generated by the combatant or none have been accepted by the station ship, all of the aforementioned request boolean

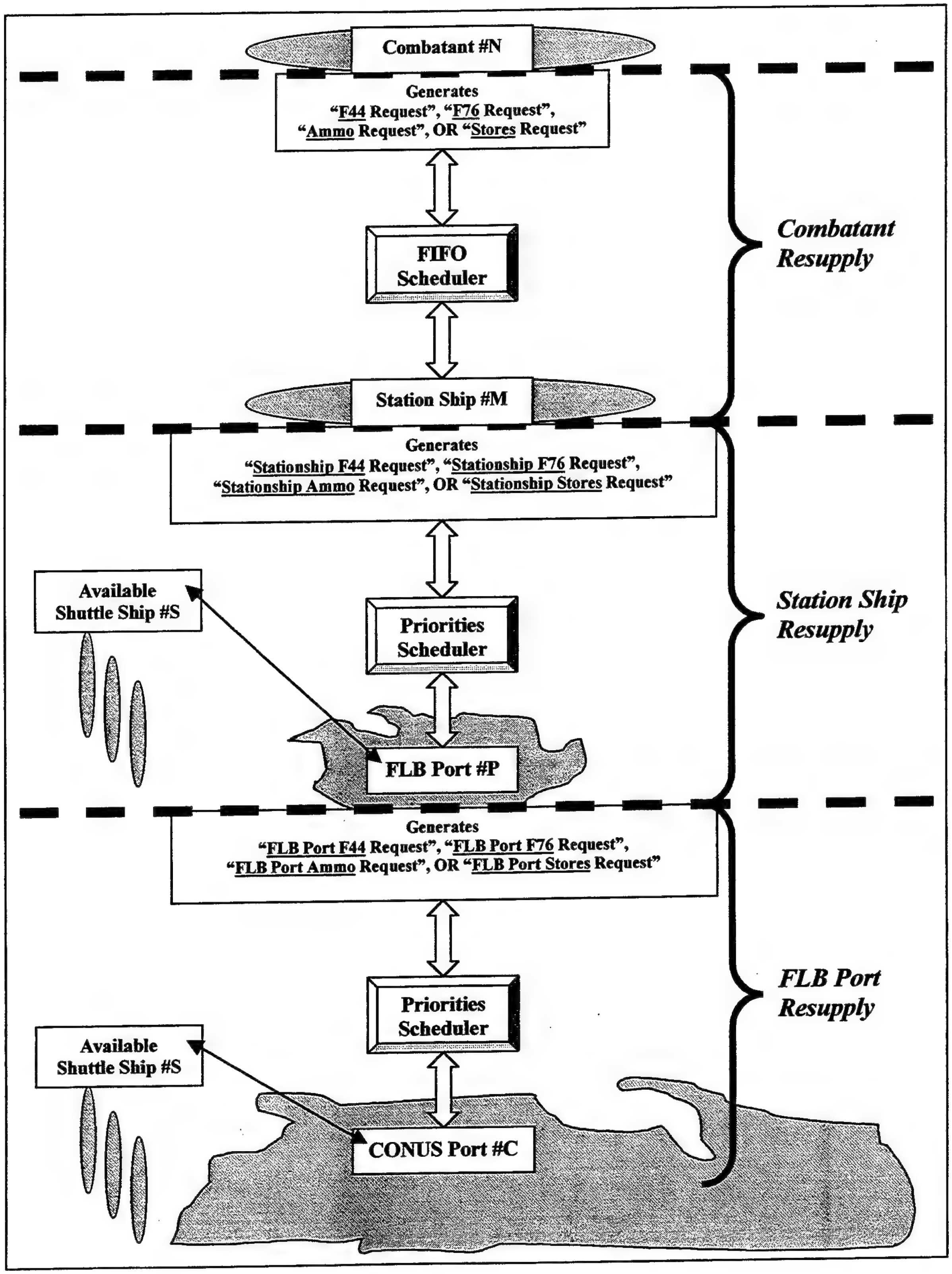


Figure 2. General Overview of BGLCAM

variables are set to "False". If all four of the request boolean variables are "False", the combatant's F76 consumption rate is obtained by randomly selecting a speed uniformly distributed between 12 and 26 knots and going to a look-up table for the corresponding rate of fuel consumption. A uniform distribution was selected for the sole purpose of modeling the fact that combatants operating in formation in the AO change speeds over time. There may be a better distribution that more closely resembles the true nature of things, but this suffices for the scope of this thesis. If any of the four request boolean variables are set to "True", the battle group speed of the combatant is used when going to the look-up tables. And lastly, the UNREP speed is used whenever the station ship is replenishing the combatant.

The other consumption rates are never randomly selected but are varied based on certain event occurrences and/or user inputs. The Stores consumption rate is the only rate that is fixed throughout the entire simulation run. This is based on the fact that there is little fluctuation in the rate of food consumption onboard similar naval vessels across different operating environments. The F44 and Ammo consumption rates, on the other hand, are based on the values that the user entered during the scenario setup. Each combatant ship can have any number of F44 and Ammo consumption rates over the duration of the battle. However, if any of the request boolean variables are "True", the F44 and Ammo consumption rates are reduced to 70% of the user-entered values. This provides a simplistic way for the combatant ship to conserve its F44 and Ammo resources when they fall below their request levels. If the combatant is being replenished by a station ship, the F44 and Ammo consumption rates are zero. This resembles the fact that combatants are not expending ordnance and conducting minimal flight operations, if at all, during UNREPs.

The user determines what level of detail he desires in the output of results by indirectly setting the number of "update events" to be scheduled during the initial setup of the program (see Appendix). Every time an update event is executed, the model checks each of the four supply categories for every ship and port to see which have fallen below their specified request levels. If the current inventory of a supply category drops below the designated request level, the applicable supply request is generated. For a combatant ship, this means a "F44 Request", "F76 Request", "Ammo Request", or "Stores Request" event will be generated.

Every combatant supply request that is generated is run through the First In First Out (FIFO) Scheduler (see Figure 2). Once a supply request enters the FIFO Scheduler,

the scheduler then checks to see if the station ship can fill any amount of the supply request. (The station ship's available supplies for UNREP are only those above the designated redline levels. Redline levels are user-specified percentages of the maximum supply inventories that can be carried on that ship.) If the station ship is unable to fill the supply request, the request is denied. If the request can be met partially or totally, the scheduler then checks to see if the station ship is currently replenishing another combatant.

If the station ship is not busy with another combatant, the scheduled time to commence replenishment with the new combatant (i.e., the join-up time) is based on the transit time between the user-designated positions of the combatant and station ship plus the combatant's UNREP approach time (see Appendix). These user-designated positions are entered during the initial setup of the program using a latitude and longitude for each ship and port. The time to cease replenishment (i.e., the breakaway time) is based on the times to conduct the Fuel At Sea (FAS) and Replenishment At Sea (RAS) rig/unrig times plus the time to replenish the combatant to full capacity, if possible, from the available station ship supplies. If the station ship is busy with another combatant, the only difference is in the computation of the join-up time. Instead of having the transit time based on the initial positions of the station and combatant ships, the transit time is calculated from the positions of the old and new combatants. These two methods for calculating the transit times mirror somewhat of a mix between the Delivery Boy and Service Station replenishment tactics, thus providing a fairly accurate way for calculating the mean inter-event times to join-up with the station ship.

These algorithms are the same for a one (i.e., AOE) or two (i.e., AO and AE) station ship battle group, but for a few exceptions. In the two-station ship battle group the combatant generates a supply request and sends it to the FIFO Scheduler. The scheduler then checks both of the station ships to see if the requested supply is available. If both of the station ships can not fill the combatant's supply request partially or totally, the request is denied. If the supply request can be met by at least one of the station ships, the scheduler schedules separately a join-up and breakaway time with both of the station ships. This means that in some instances, the scheduler will establish for the combatant a join-up and breakaway time with a station ship that can not fill its supply request. However, this is done to allow for the possibility that the station ship has supplies in one or more of the other categories available for transfer. Furthermore, if it happens that the station ship has no categories of supplies available for transfer, the breakaway time will only equal the sum of the times to conduct the Fuel At Sea (FAS) and Replenishment At

Sea (RAS) rig/unrig times. This is because the time to UNREP is zero in the case of no supply types being available for transfer. In essence, the model simulates wartime underway replenishment tactics, which allows for a combatant to be replenished by an AO and AE at the same time.

C. STATION SHIP RESUPPLY

The following is an explanation of the modeling methods used to mirror the tactics for the replenishment of station ships operating with carrier or amphibious battle groups. As a station ship's supplies are delivered to the combatants it becomes necessary for the station ship to be replenished by a shuttle ship operating out of a FLB. The four possible requests that a station ship can generate are the "Stationship F44 Request", "Stationship F76 Request", "Stationship Ammo Request", and "Stationship Stores Request". A supply request from a station ship is generated in the same way as a combatant. Once a supply request is generated, it goes to the Priorities Scheduler (see Figure 3). When the scheduler receives a supply request it checks to see if one of several conditions are met. It always begins with the first of the four such conditions, which are numbered one through four (i.e., "Step#1", "Step#2", "Step#3", "Step#4") in Figure 3. For clarity of presentation, the algorithms used in this scheduler are presented in a pseudo-code format, seen in Figure 3.

PRIORITIES SCHEDULER

Step#1 *If Station Ship Generates A F44, F76, Ammo,* **OR** *Stores Request, Scheduler Checks For Nearest FLB Port With An Available Shuttle Ship That Has F44, F76, Ammo,* **AND** *Stores Available For Transfer:*

- **If No Shuttle Ships Meet Step#1 Conditions:** ***Go to*** **Step#2**
- **If A Shuttle Ship Meets Step#1 Conditions:** ***Go to*** **Subroutine Compute**

Step#2 *If Station Ship Generates A F44, F76,* **OR** *Ammo Request, Scheduler Checks For Nearest FLB Port With An Available Shuttle Ship That Has F44, F76,* **AND** *Ammo Available For Transfer:*

- **If No Shuttle Ships Meet Step#2 Conditions:** ***Go to*** **Step#3**
- **If A Shuttle Ship Meets Step#2 Conditions:** ***Go to*** **Subroutine Compute**

Step#3 *If Station Ship Generates A F44, F76, Ammo,* **OR** *Stores Request, Scheduler Checks For Nearest FLB Port With An Available Shuttle Ship That Has F44, F76, Ammo,* **OR** *Stores, Respectively, Available For Transfer:*

- **If No Shuttle Ships Meet Step#3 Conditions:** ***Go to*** **Step#4**
- **If A Shuttle Ship Meets Step#3 Conditions:** ***Go to*** **Subroutine Compute**

Step#4 *If None Of The Conditions Are Met In Step#1, Step#2,* **AND** *Step#3:*

- **Deny The Station Ship's Supply Request**
- **Exit Priorities Scheduler**

Subroutine Compute:

- Let **CUT** = the current simulation time
  SST = the time it takes the shuttle ship to travel from the sending port to the station ship
  F44UT = the time to transfer 115% of the amount of F44 needed by the station ship
  F76UT = the time to transfer 115% of the amount of F76 needed by the station ship
  AmmoUT = the time to transfer 115% of the amount of Ammo needed by the station ship
  StoresUT = the time to transfer 115% of the amount of Stores needed by the station ship
  IPT = the inport time, a random variable uniformly distributed between 0.5 and 1.5
- Compute Time For Shuttle Ship To Begin Replenishing Station Ship, i.e., the Join-up Time (JUT):
  JUT = CUT + SST
- Compute Time To Cease Replenishing Station Ship, i.e., the Breakaway Time (BAT):
  BAT = JUT + Maximum{ F44UT, F76UT, AmmoUT, StoresUT}
- Compute Time When Shuttle Ship Is Available For Other Supply Requests, i.e., the Port Return Time (PRT):
  PRT = BAT + SST + IPT
- Exit Priorities Scheduler

Figure 3. Station Ship Resupply Priorities Scheduler

As can be seen from the explanation given in Figure 3, the distance between the station ship and the sending FLB port has been chosen as the primary determinant for choosing a shuttle ship, followed by the type of request that is generated by the station ship. This makes sense when one considers the goal of the basic concept of operations for battle group logistical support, which is to enable the battle group to conduct continuous operations in the AO. FLB ports closer to the AO mean shorter cycle times for the CLF shuttle ships transiting between the ports and the station ship. Given that everything else

is fixed, these shorter cycle times equate to higher levels of supplies being maintained on the combatants and fewer CLF shuttle ships needed at the FLB ports.

D. FLB PORT RESUPPLY

Out of the three major sections to this model (see Figure 2), the FLB Port Resupply section is the most basic. It was designed to provide some general information for the amount and frequency of shuttle shipping necessary to sustain the FLBs. However, it was never intended to capture the reality of the surge in shuttle ship traffic that takes place during the initial days of most conflicts.

As with the previously mentioned object types, there are four requests that a FLB port can generate: a "FLB Port F44 Request", "FLB Port F76 Request", "FLB Port Ammo Request", and "FLB Port Stores Request". Once a FLB Port has a supply request, it is sent to the Priorities Scheduler (see Figure 4). As before, the algorithms used in this scheduler are explained in a figure (see Figure 4) for clarity of presentation.

PRIORITIES SCHEDULER

Step#1 *If FLB Port Generates A F44, F76, Ammo,* **OR** *Stores Request, Scheduler Checks For Nearest CONUS Port With An Available Shuttle Ship That Has F44, F76, Ammo,* **AND** *Stores Available For Transfer:*

- **If No Shuttle Ships Meet Step#1 Conditions:** ***Go to*** **Step#2**
- **If A Shuttle Ship Meets Step#1 Conditions:** ***Go to*** **Subroutine Compute**

Step#2 *If FLB Port Generates A F44, F76,* **OR** *Ammo Request, Scheduler Checks For Nearest CONUS Port With An Available Shuttle Ship That Has F44, F76,* **AND** *Ammo Available For Transfer:*

- **If No Shuttle Ships Meet Step#2 Conditions:** ***Go to*** **Step#3**
- **If A Shuttle Ship Meets Step#2 Conditions:** ***Go to*** **Subroutine Compute**

Step#3 *If FLB Port Generates A F44, F76, Ammo,* **OR** *Stores Request, Scheduler Checks For Nearest CONUS Port With An Available Shuttle Ship That Has F44, F76, Ammo,* **OR** *Stores, Respectively, Available For Transfer:*

- **If No Shuttle Ships Meet Step#3 Conditions:** ***Go to*** **Step#4**
- **If A Shuttle Ship Meets Step#3 Conditions:** ***Go to*** **Subroutine Compute**

Step#4 *If None Of The Conditions Are Met In Step#1, Step#2,* **AND** *Step#3:*

- **Deny The FLB Port's Supply Request**
- **Exit Priorities Scheduler**

Subroutine Compute:

- Let **CUT** = the current simulation time
  SST = the time it takes the shuttle ship to travel from the sending CONUS Port to the FLB Port
  IPT = the inport time, a random variable uniformly distributed between 0.5 and 1.5
- Compute Time For Shuttle Ship To Begin Replenishing FLB Port, i.e., the Join-up Time (JUT):
  JUT = CUT + SST
- Compute Time To Cease Replenishing FLB Port, i.e., the Breakaway Time (BAT):
  BAT = JUT + IPT
- Compute Time When Shuttle Ship Is Available For Other Supply Requests, i.e., the Port Return Time (PRT):
  PRT = BAT + SST + IPT
- Exit Priorities Scheduler

Figure 4. FLB Port Resupply Priorities Scheduler

As can be viewed from the description given in Figure 4, the algorithm for the FLB Port Resupply Priorities Scheduler is the same for that used in the Station Ship Resupply Priorities Scheduler except in a few points. This represents the fact that the same basic model exists for the sustainment of the FLBs and the support to the battle groups operating in the AO, i.e., the shuttle ship travels from the port of loading to its receiver and back again. It doesn't account for the reality when shuttle ships make multiple port visits before they reach their final drop-off point. Nor does it provide a look-ahead optimizer scheduler to see which is the best course for sustaining the FLB ports. It simply provides shuttle shipping, if available, on demand.

III. BGLCAM APPLICATIONS

A. TWO SCENARIO IMPLEMENTATIONS

The following is a hypothetical scenario that was developed for the sole purpose of illustrating some of the capabilities of the BGLCAM. It is not intended to produce "real world" results since the scope of this thesis is to remain unclassified.

Imagine an aircraft carrier battle group that operates approximately 150 nautical miles off of the eastern coast of North Korea. There are two Aegis cruisers (CG-47), one Arleigh Burke destroyer (DDG-51), two Oliver Hazard Perry frigates (FFG-7), one conventional aircraft carrier (CV), one oiler (AO), and one ammunition (AE) ship that make up the battle group. The relative positions of the naval vessels are as seen in Figure 5.

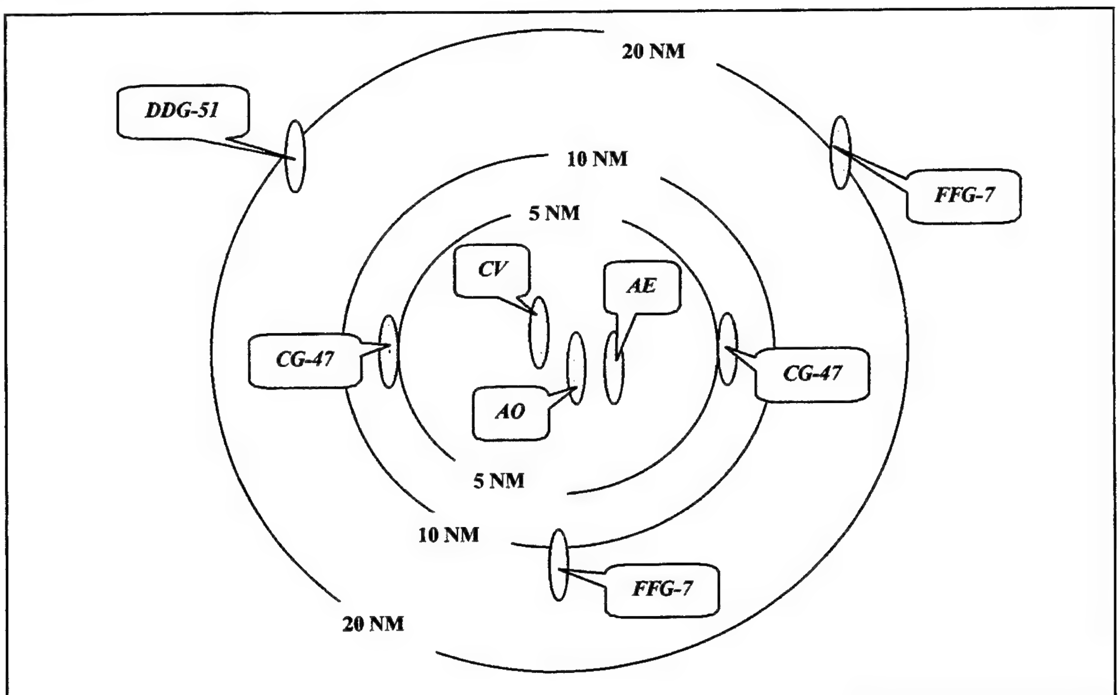


Figure 5. CV Battle Group Formation

The nearest Forward Logistics Base from which the CLF shuttle ships operate is Yokohama, Japan, which is over 570 nautical miles (NM) away by way of the great circle distance. The shuttle ships that operate from this port in direct support of the battle group are two ammunition (AE) ships, one stores (AFS) ship, and three oiler (AO) ships.

The ships of the battle group arrive on station on Day Zero with the following inventories (see Table 1).

Ship Type	F44 Max (bbls)	F44 Onhand (bbls)	F76 Max (bbls)	F76 Onhand (bbls)	Ammo Max (tons)	Ammo Onhand (tons)	Stores Max (tons)	Stores Onhand (tons)
CV	**46272**	**46272**	**55363**	**55363**	**900**	**900**	**1575**	**1575**
CG47	**1000**	**1000**	**15800**	**15800**	**100**	**100**	**108**	**108**
CG47	**1000**	**1000**	**15800**	**15800**	**100**	**100**	**108**	**108**
DDG51	**1000**	**1000**	**12800**	**12800**	**100**	**100**	**99**	**99**
FFG7	**400**	**400**	**4600**	**4600**	**30**	**30**	**72**	**72**
FFG7	**400**	**400**	**4600**	**4600**	**30**	**30**	**72**	**72**
AO	**83000**	**83000**	**100000**	**100000**	**600**	**600**	**300**	**300**
AE	**2000**	**2000**	**16800**	**16800**	**2000**	**2000**	**117**	**117**

Table 1. Day Zero Ship Inventories

Additionally, the following request (designated by "Req") and redline (designated by "Red") levels are set (see Table 2). Each level is a certain percentage of the applicable supply capacity. The request levels determine when a ship can begin sending out requests. The redline levels (station ships only) set the levels at which the station ships must cease transferring the applicable supply.

Ship Type	F44 Req(%)	F44 Red(%)	F76 Req(%)	F76 Red(%)	Ammo Req(%)	Ammo Red(%)	Stores Req(%)	Stores Red(%)
CV	**70**	**50**	**70**	**50**	**70**	**50**	**70**	**50**
CG47	**70**	**50**	**70**	**50**	**70**	**50**	**70**	**50**
CG47	**70**	**50**	**70**	**50**	**70**	**50**	**70**	**50**
DDG51	**70**	**50**	**70**	**50**	**70**	**50**	**70**	**50**
FFG7	**70**	**50**	**70**	**50**	**70**	**50**	**70**	**50**
FFG7	**70**	**50**	**70**	**50**	**70**	**50**	**70**	**50**
AO	**70**	**10**	**70**	**30**	**70**	**5**	**70**	**30**
AE	**70**	**5**	**70**	**50**	**70**	**10**	**70**	**30**

Table 2. Ship Request and Redline Levels

As soon as the battle group arrives in the area of operations (AO), moderate flight operations commence. From Days Zero through 15 operations are relatively the same. After Day 15 the North Koreans launch a massive ground attack into South Korea. Thus, on Days 16 through 60 the battle group shifts to a role of defense which acts in support of the American and South Korean ground forces. After more men and supplies are moved into the AO, the American-led coalition forces transition to an offensive battle phase. This offensive phase lasts from Days 61 to 75. Finally, after a bloody battle, the North Koreans surrender unconditionally on Day 75. However, the naval battle group continues to conduct flight operations within the AO for an additional two weeks during the withdrawal phase.

The following table (see Table 3) contains the ammunition (Ammo) and aviation fuel (JP-5) mean consumption rates used for each combatant during the different phases of battle.

JP-5 and Ammo Consumption Rates Are In Units of pounds / man / day.

Ship Type	**JP-5** Days 0-15 PreWar	**Ammo** Days 0-15 PreWar	**JP-5** Days 16-60 Defense	**Ammo** Days 16-60 Defense	**JP-5** Days 61-75 Offense	**Ammo** Days 61-75 Offense	**JP-5** Days 76-90 Peace	**Ammo** Days 76-90 Peace
CV	**111**	0	**155**	125	**200**	195	**130**	0
CG47	**111**	0	**155**	46	**200**	71	**130**	0
CG47	**111**	0	**155**	46	**200**	71	**130**	0
DDG51	**111**	0	**155**	123	**200**	190	**130**	0
FFG7	**111**	0	**155**	32	**200**	40	**130**	0
FFG7	**111**	0	**155**	32	**200**	40	**130**	0

Table 3. JP-5 and Ammo Consumption Rates

The JP-5 "burn rates" in Table 3 are based on some unclassified Desert Storm carrier battle group data [Ref. 3], while the Ammo consumption rates are approximations of some unclassified data developed for a TACWAR scenario. All supplies needed by the Forward Logistics Base, Yokohama, are being sent from two Continental United States (CONUS) ports: Oakland, California and Pearl Harbor, Hawaii. There are two shuttle ships at each of these two ports moving the needed supplies when requested.

The scenario just described was implemented (using 50 replications) into the BGLCAM with an update scheduled every 12 hours over the whole duration of the 90-day battle. After this first scenario implementation, a second scenario was implemented using a modified version of the first scenario. In this second scenario the FLB port was changed to Guam, while everything else was kept the same as in the first scenario. What follows are two figures that illustrate in a chart format the statistical results obtained from the two model runs (see Figure 6 and Figure 7). Next are Figure 8 and Figure 9 which give a graphical sampling of the output of results for the day-to-day inventory levels for each of the four categories of supplies onboard the two station ships, AO-2 and AE-2, respectively.

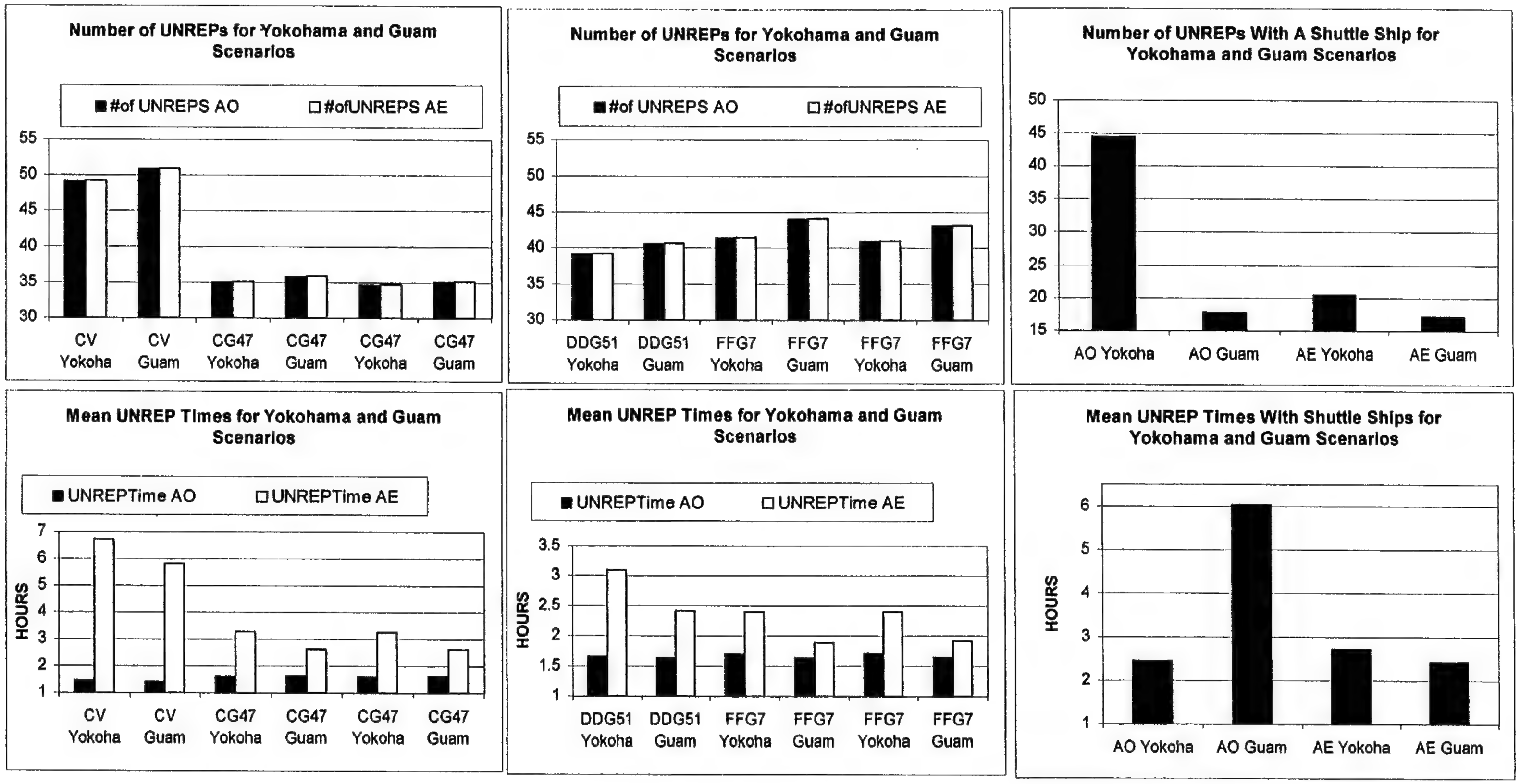


Figure 6. Number of UNREPs and Mean UNREP Times for Each Ship In Yokohama and Guam Scenarios

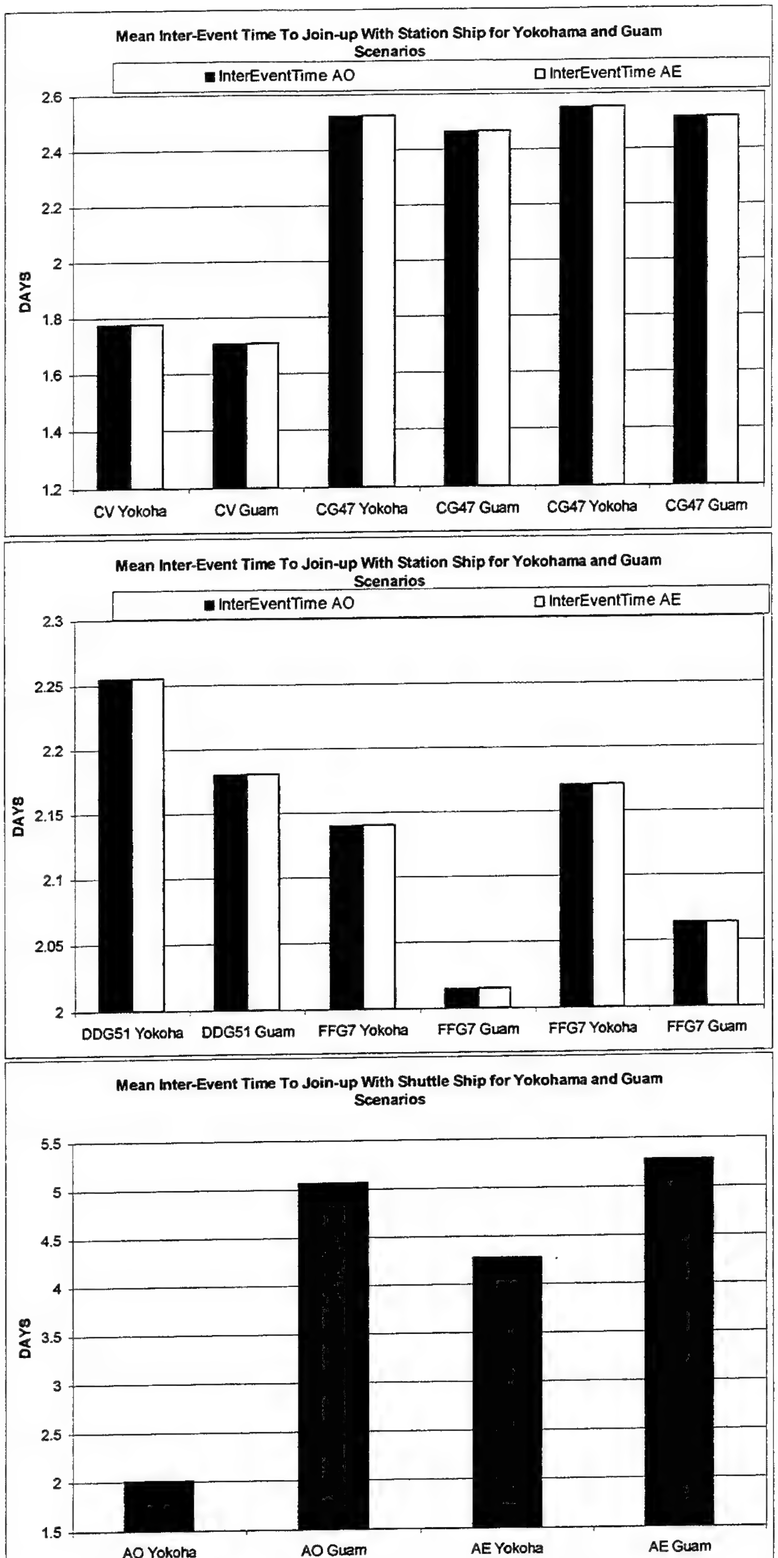


Figure 7. Mean Inter-Event Times To Join-up for Yokohama and Guam Scenarios

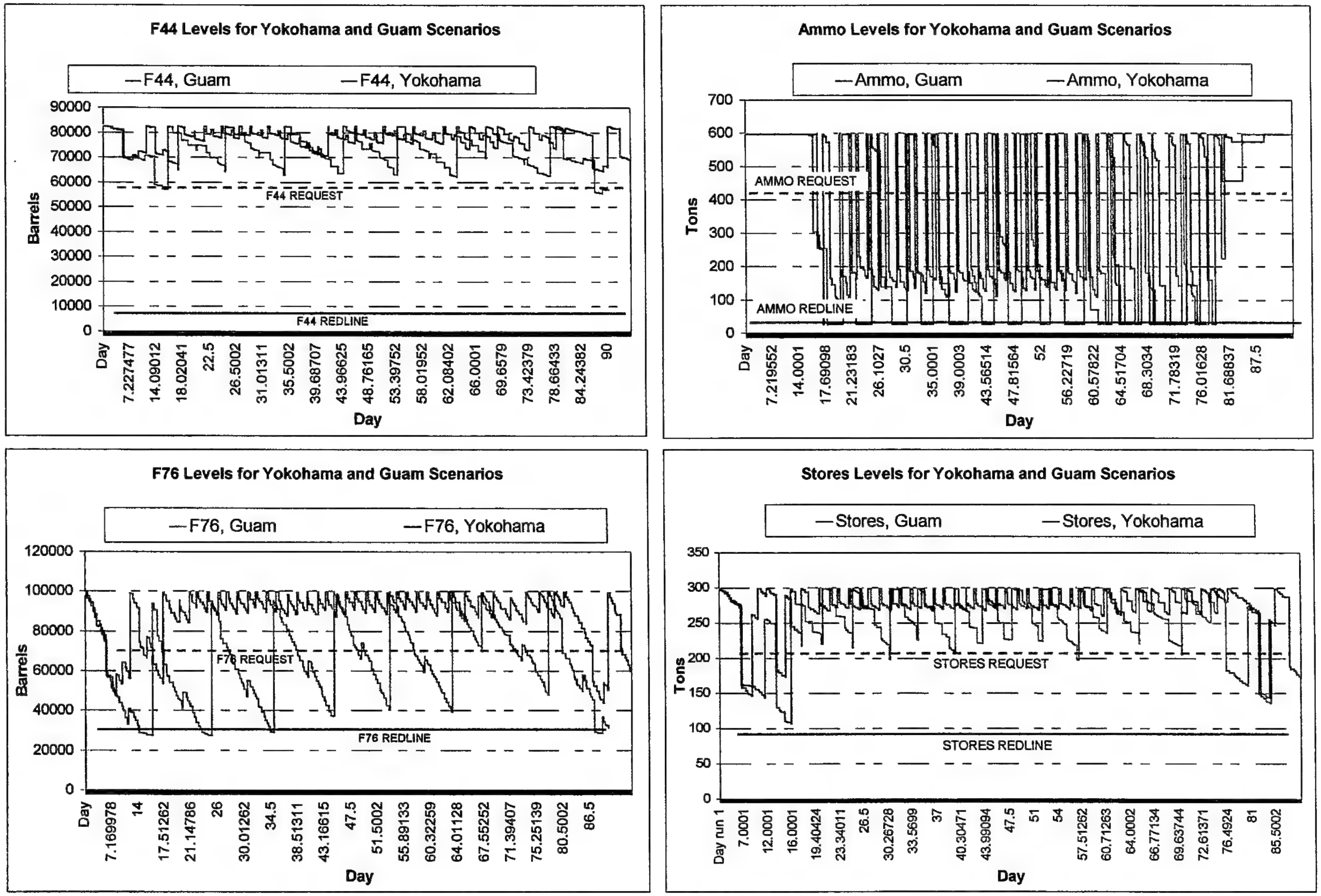
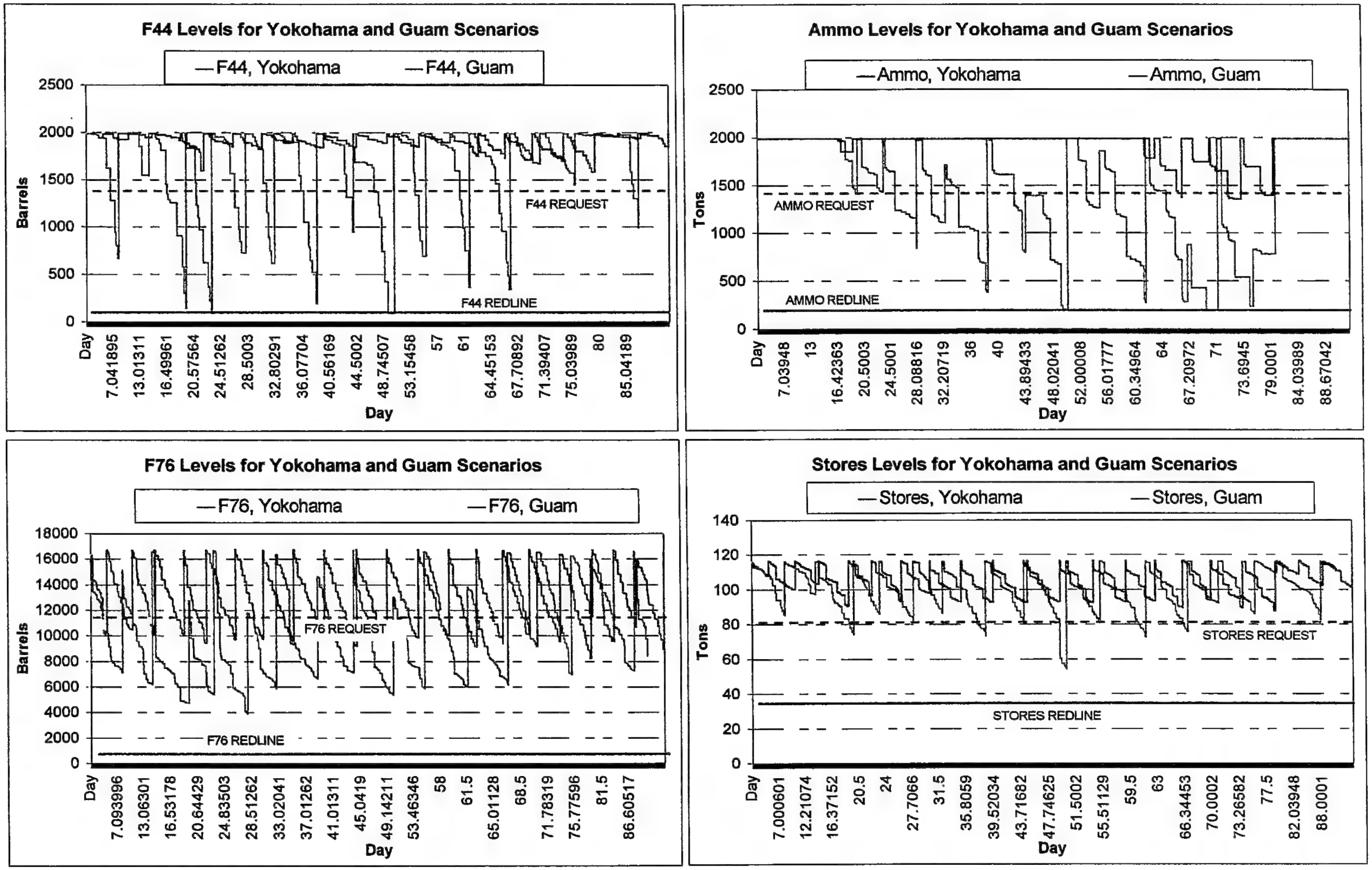


Figure 8. AO-2: F44, F76, Ammo, Stores for Yokohama and Guam Scenarios

Figure 9. AE-2: F44, F76, Ammo, Stores for Yokohama and Guam Scenarios



The real benefits in using BGLCAM come when the output of results are imported into a spreadsheet model as shown previously in Figure 1. This allows the user to use whatever capabilities the spreadsheet model has for analyzing data. Most spreadsheet models offer the capability to graph data, allowing plots of the day-to-day inventories for each of the ships and ports, so that areas which deserve further investigation may be readily identified.

Considering the hypothetical scenario described earlier, Figure 6 and Figure 7 provide a quick way to visually verify some outcomes when the FLB port is moved farther away from the battle group. The time a combatant spent in UNREPs with the station ships decreased significantly when the FLB port was moved to Guam. This implies that the station ships' inventory levels in the Guam scenario were, on average, much lower than in the Yokohama scenario. Therefore, the station ships spent less time replenishing the combatants since they had fewer supplies to give to the combatants. Furthermore, Figure 6 shows a slight increase in the number of UNREPS that the station ships had had with the combatants when the FLB port was moved to Guam. This means that the station ships in the Guam scenario had, on average, a slightly greater frequency of UNREPs with the combatants, but with smaller durations. This corresponds with the results displayed in Figure 7 which show that the mean inter-event times to join-up with the station ships for the six combatants decreased when the FLB port was moved farther away.

Figures 6 and 7 also show an inverse relationship between the combatant ships and station ships. In particular, the number of combatant UNREPS with the station ships increased slightly moving to Guam, while the number of station ship UNREPs with the shuttle ships decreased. Additionally, all but one of the mean UNREP times and all of the mean inter-event times to join-up with the shuttles ships increased going to the Guam scenario, while the combatant mean UNREP times and the mean inter-event times to join-up with the station ships decreased.

Although BGLCAM provides some built-in features that keeps track of certain statistical information (as displayed in a chart format in Figure 6 and Figure 7), it does not provide the amount of information that the spreadsheet output provides. Looking at Figure 8 and Figure 9, it is easier to determine which supply categories were in demand the most for the different phases of battle. It is also easier to see that the average amount of supplies onboard the station ships, AO-2 and AE-2, are lower at any given time for the Guam scenario than they are for the Yokohama scenario. Additionally, a graphical display of the day-to-day inventory levels allows identification of increases or decreases in

the number of times that a ship's levels fall below redline. In our case, AO-2 fell to its Ammo redline level almost twice as much in the Guam scenario than it did in the Yokohama scenario.

More information can be gleaned from the spreadsheet output of results, but the previous discussion of the different ways to analyze the data suffices for the scope of this thesis.

B. ADDITIONAL SCENARIO IMPLEMENTATIONS

Every reasonable effort has been made to confirm the algorithms used in the computer program, as well as the output that it produces. Every procedure and function within the program has been checked dynamically line by line using the Microsoft Visual Basic 5.0 compiler. Different sets of data and over 40 various scenarios have been entered and checked for accuracy of performance by comparing the computer-generated results with those obtained by the use of a hand-held calculator. Computational formulas used in the program were verified multiple times by going through the day-to-day outputs for both a 90-day and 50-day battle. Runs have been successfully done with scenarios containing multiple battle groups, ports, and shuttle ships.

Lastly, the results of several different model runs were discussed with some naval officers familiar with battle group logistics. The mean UNREP times and the mean inter-event times to join-up coincided with the times experienced by the naval officers in actual fleet operations. These confirmations were obtained when using unclassified ship performance data.

IV. CONCLUSIONS

A. SUGGESTED MODEL IMPROVEMENTS

The BGLCAM is a modular-designed program that allows future modifications with relative ease. Some recommended improvements to the model include the following.

1. Modify the program such that a user can schedule several "Sink Combatant" events before the simulation is run. This change will allow for studies into the effects of a ship being sunk at some time into the game. It will also improve the model's compatibility with some of the theater level combat simulations by allowing the user to script the exact naval scenario generated by them, which may include hostile action.
2. Create some statistical counters that keep track of the number of times a combatant falls below one of its redline levels and modify the on-screen output seen by the user accordingly.
3. Design a routine that will automatically extract the day-to-day information for a particular ship or port, and then have it placed into a separate output file. This capability will free the user from having to do multiple sorts while manipulating the data in a spreadsheet model.
4. Modify the computer program so that a combatant only tasks each station ship in a two-station ship battle group when the station ship can partially or totally fill the request generated by the combatant.
5. Develop procedures (e.g., list boxes) within the computer program that will limit the user to entering only the data that is eligible for entry. This change should reduce the amount of possible user-input errors.

B. MODEL SUMMARY

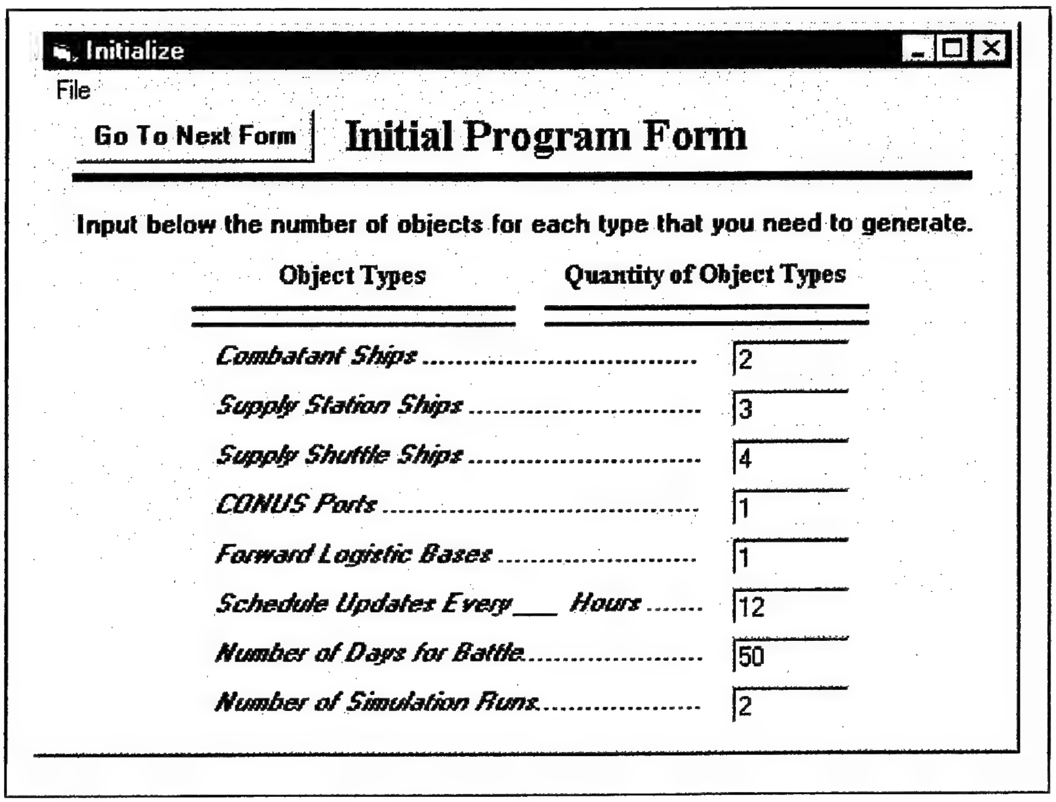
The BGLCAM is a tool that aids the analyst in doing comparative analyses of the different aspects involved in multi-battle group logistics support. While the model does not give a detailed (i.e., high resolution) view of battle group logistics support, it does model the basic concept of operations, as previously discussed. The model provides a theater-level representation of battle group logistics support, not an operational-level view. Because of the low resolution of this model, it is recommended that it be used only

for its designed purposes. Lastly, the BGLCAM is available on request from Professors Mark Youngren or Arnold Buss of the Operations Research Department at the Naval Postgraduate School, Monterey, California.

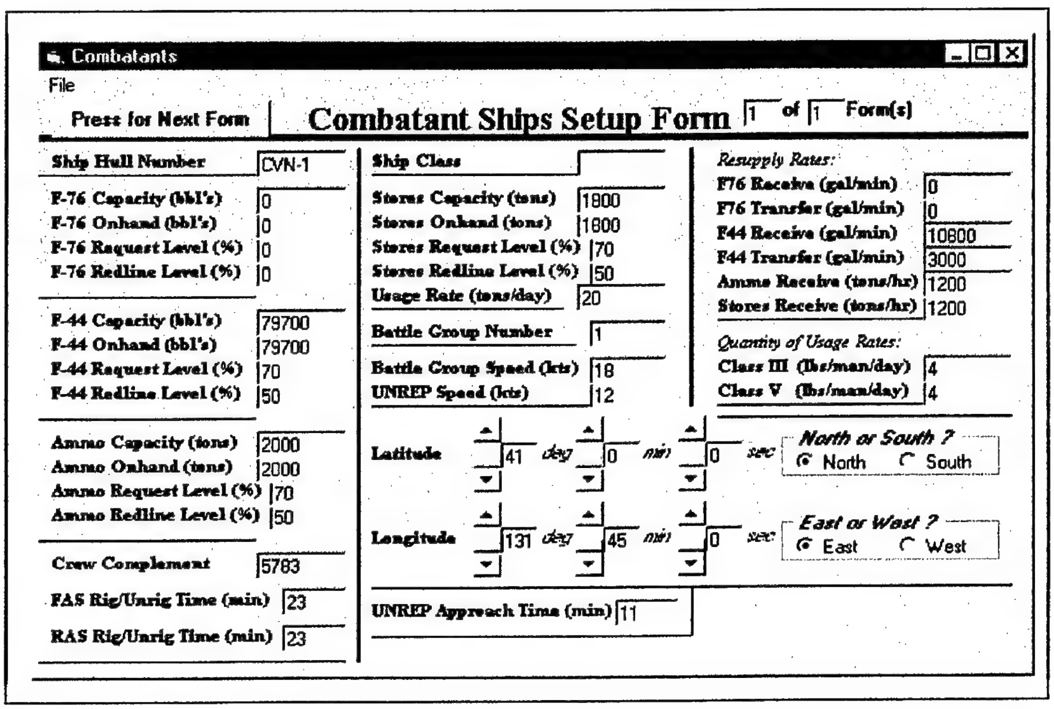
APPENDIX. BGLCAM WINDOWS VIEWED BY THE USER

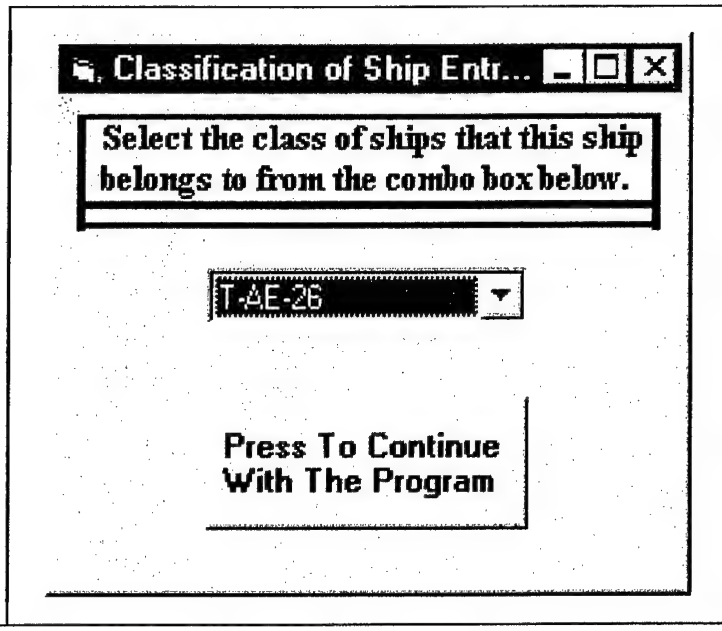
Below is the first form that the user sees after starting the program. The data for this form can be entered from the keyboard or from a text file that was previously saved while using the program. There are several things that must be done by the user if the program is to run properly. They include the following.

1) Enter the total number of combatants for all of the battle groups in the corresponding "Combatant Ships" textbox.
2) Do the same, as in number one, for the station ships.
3) Give each battle group only one or two station ships apiece (no more or no less).
4) Ensure that every FLB port and CONUS port has at least one shuttle ship assigned to them.

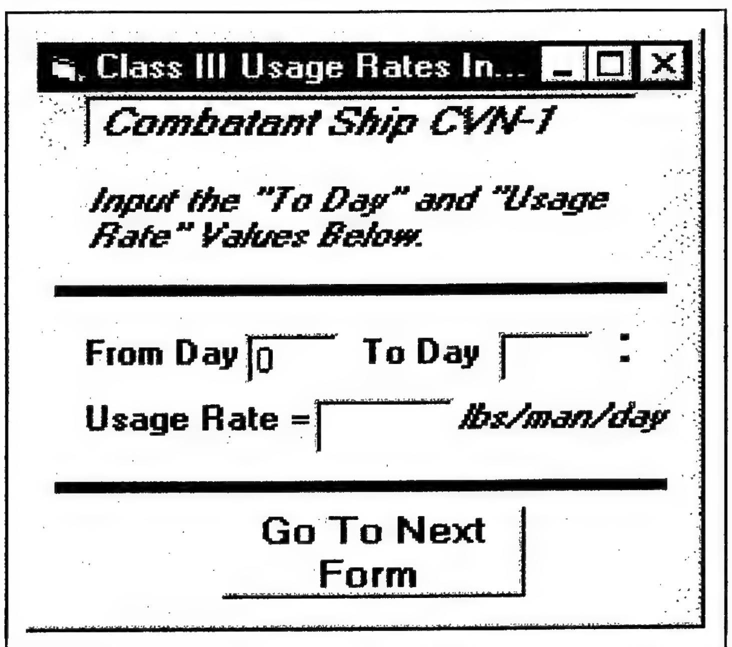


Below is the Combatant Ships Setup Form. As in the Initial Program Form, the user can also enter data onto this form from the keyboard or from a text file. Most of the information that is entered on this form is self-explanatory. However, there are a few things that need to be mentioned. The redline levels for each of the categories of supplies do nothing in this program. They are hooks for future modifications to the program. The Class III and Class V Quantity of Usage Rates boxes are where the user enters the number of time periods for which there are different Class III and Class V consumption rates, respectively, over the duration of the battle. Be sure to give a unique name to each combatant and make sure to enter the appropriate battle group number to which the combatant belongs. There are few checks for user input errors in this program so be sure that all data are entered correctly before proceeding to the next form.



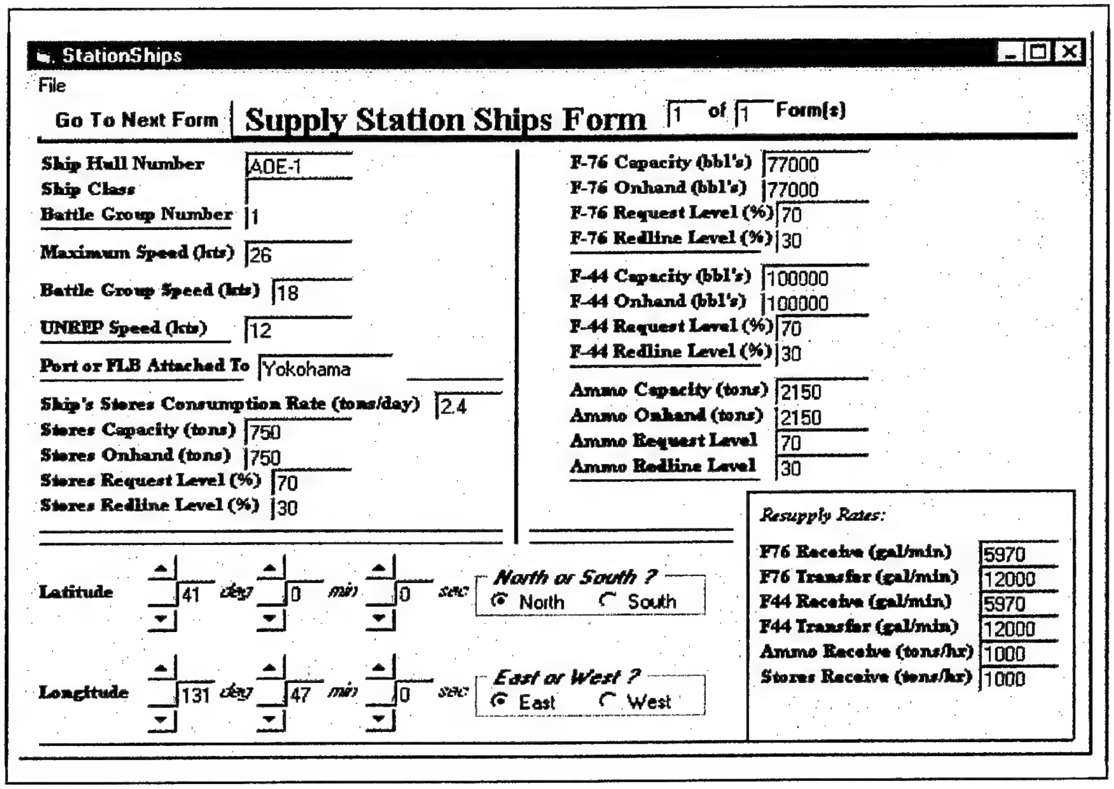


This window appears for each combatant, station, and shuttle ship that is created. The selection defines which ship propulsion fuel (F76) consumption rate tables to go to when needed.

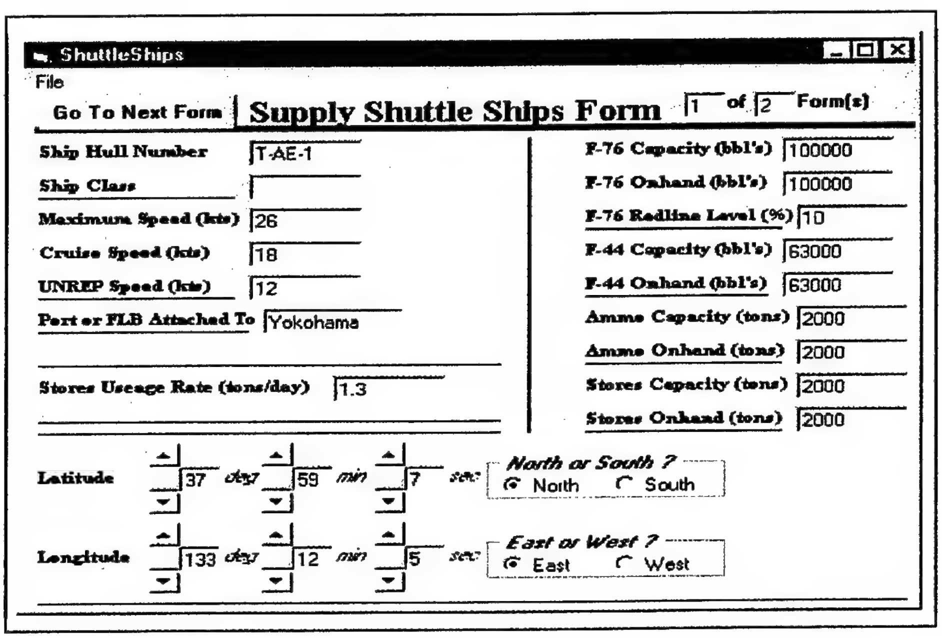


This same Window appears to the user for both the Class III (JP-5) and Class V (Ammunition) consumption rates.

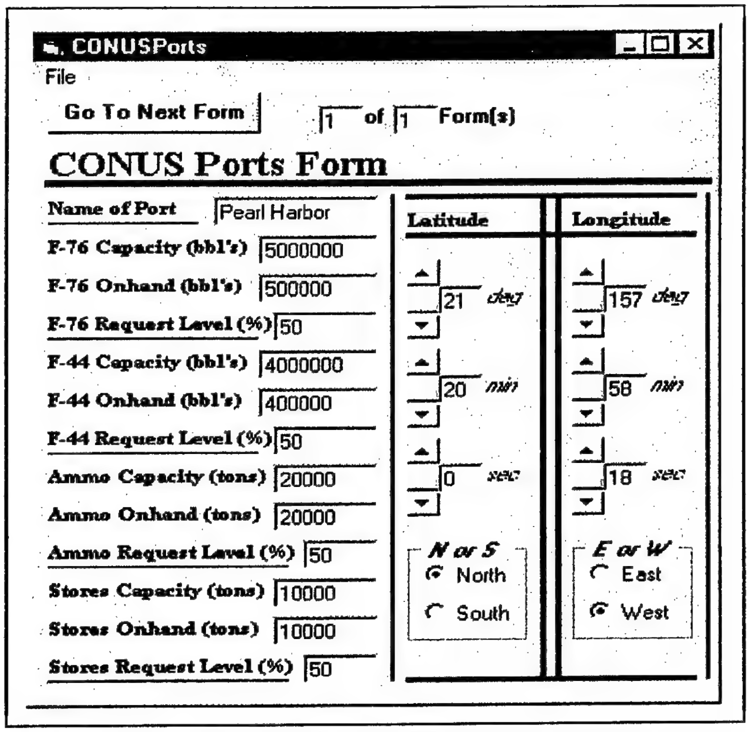
A note of caution when using the Supply Station Ships Form. Be sure to assign the station ship to the correct battle group number.

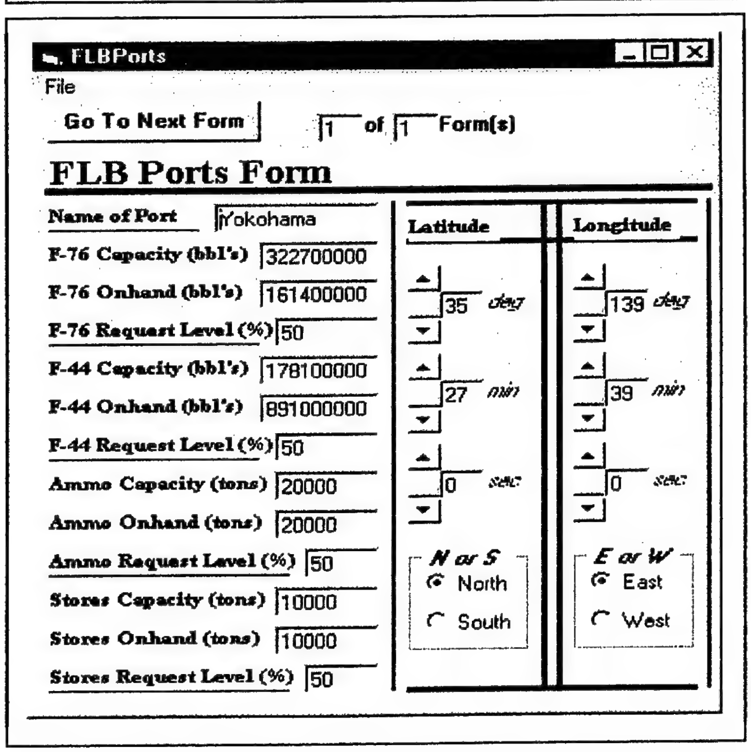


Be sure to enter the correct port name into the "Port or FLB Attached To" textbox, since it is case sensitive.

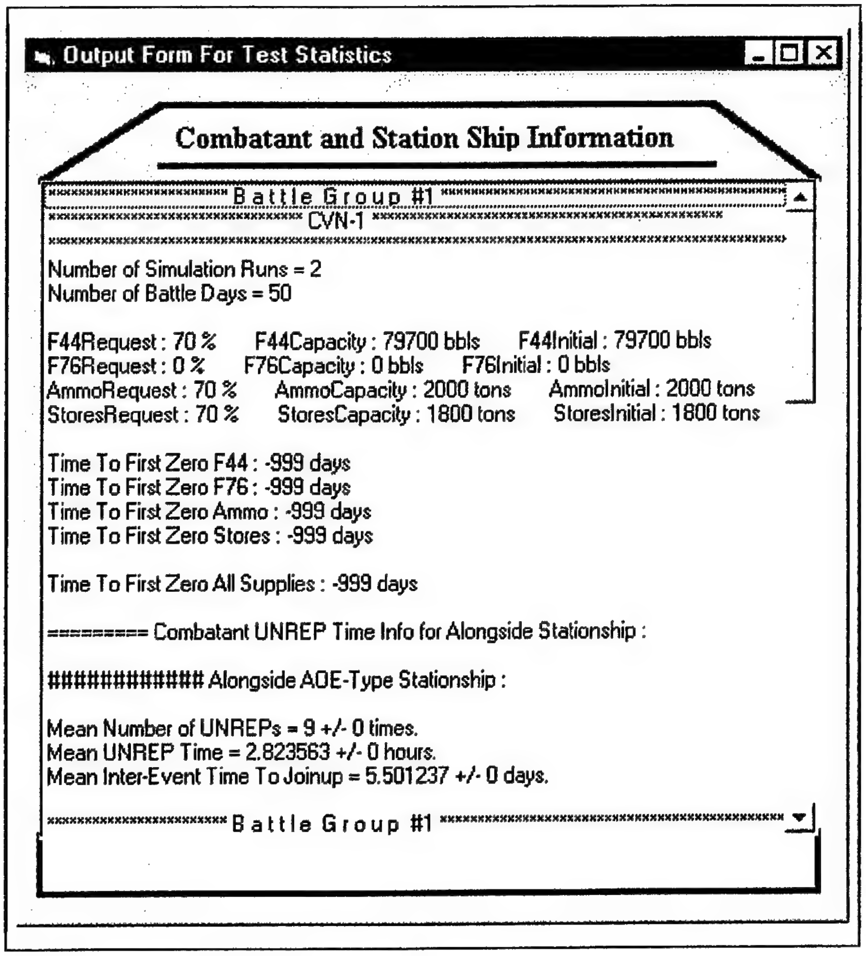


The same port attachment warning applies to the CONUS Ports Form and the FLB Ports Form. Be sure to enter the correct name into the "Name of Port" textbox since it is case sensitive.





The Combatant and Station Ship Information Form is simply a visual display of a few basic statistical results obtained from running the program. The "Time To First Zero…" entries indicate the first time that a particular ship's respective category of supply goes to zero. The same applies to the "Time To First…Request" entries. The values, "-999", when seen, are simply dummy values that indicate that there was no such time that the particular event occurred.



LIST OF REFERENCES

1. Schrady, D. A., "Measures of Effectiveness In Logistics", Naval Postgraduate School, NPS 55-89-07, May 1989.

2. Schrady, D. A., "Operational Logistics: OA 3610, Introduction to Naval Logistics", notes given in OA 3610 class, February 1997.

3. Commander Logistics Group, Western Pacific, "PETROLEUM SUPPORT FOR SEVENTH FLEET", Ser N7/0008, January 14, 1993.

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